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(63)*

Analysis of the spectral characteristics of sound signals emitted by pinnipeds

by V.A. Svizhenko

Sound signaling in pinnipeds has been very poorly researched so far, but many of the researchers studying the behaviour of these animals assume that sound must play an important role in their life. By means of sound signals, the animal usually keeps in touch with the others of the herd, letting them know of its whereabouts, as well as warns and challenges its rivals, calls to its mate or partners in the group, etc. Some authors (Poulter, 1963; Schewill, Watkins and Ray, 1963) who have recorded underwater sounds believe that pinnipeds can use them for the purpose of orientation in the underwater world surrounding them. It is important to study the acoustic characteristics of pinnipeds when dealing with problems related to their conservation for efficient commercial utilization, and developing systems of controlling their behaviour.

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Sound signals emitted by pinnipeds even at the level of one individual are highly variable. These animals bellow, cough, gurgle, clatter their teeth, growl, emit a soft warning whistle and other sounds. The interpopulational, intraspecific and often interspecific differences "drown" in this individual variability. Therefore, we first had to attain a stable and consistent assessment of the signals, and then go on to describe the zoologically interesting features of their communication under various conditions. Unfortunately, the problem of "combatting variability" and obtaining stable and reliable results has not been completely solved yet, and so the procedural approaches described in this paper can be useful for solving only certain aspects of this problem.

While studying this question, we found that the signaling process in pinnipeds is of a random nature, and so we found it impossible to avoid using the methodology of analyzing random acoustic processes. The introduction of this methodology complicates the processing of data, but it is predetermined by the structural characteristics of the pinniped signals. (64)

Material and methods

The study of communication sound signals in pinnipeds was carried out in two stages. The signals were first recorded under natural conditions, and then they were processed in a laboratory. The sound signals of the harbour seal (Phoca vitulina L.) and the northern sea-lion (Eumetopias jubatus Schreber) were recorded during the 1978 Far Eastern

expedition (Sakhalin Is., Kurile Islands) of the Physical Etiology Laboratory of the Institute of Zoology of the Ukrainian Academy of Sciences, while the signals of the bearded seal (Erignatus barbatus Erzleben) and the walrus (Odobenus rosmarus L.) were obtained by the VNIIRO expedition (Chukchi and Barents seas) in 1977-1979 and submitted to us for processing by A. Kibalchich. The signals were recorded on the "Sputnik-1M" and "Reporter-2" tape-recorders, and a piezoelectric sphere with a diameter of 5 cm was used as the sound-detecting element. The measurements were taken underwater within a frequency range of 80-8000 Hertz. In order to eliminate the effect of sea surface noises, the hydrophones were immersed to a depth of up to 2 m.

At the second stage of the study, in the Physical Etiology Laboratory, the recordings were analyzed in order to classify both the signals themselves, and the animals by their signals. Random time samples of the signals served as the initial material for analysis.

Bioacoustic signals are predominantly transient random processes. Even in the case where successive signals of the same animal are recorded, their characteristics differ significantly on account of the variability of the parameters of the vocal apparatus. The energy spectra of successive sound signals (fig. 1) emitted by the members of three families of pinnipeds, i.e. the harbour seal belonging to the true seals (Phocidae), the northern sea-lion belonging to the eared seals (Otarriidae) and the walruses (Odobenidae),

though they are similar on the whole, do not coincide, and vary in a random manner. That is, the obtained energy spectral characteristics, the values of which are proportional to signal dispersion, are time-dependent, which points to the transient nature of the measured bioacoustic process. Analysis of such processes is based on the averaging of the obtained variable spectral characteristics for the whole set of signals (Romanenko, 1974). One could simply average the obtained energy spectra point by point, and arrive at the mean spectrum, the time-dependence of which would be somewhat smaller, given a large number of signals. However, we were interested in establishing the stable characteristics in the sound signals, i.e. obtaining the characteristics which would allow us to eliminate the influence of individual signal variability.

(65)

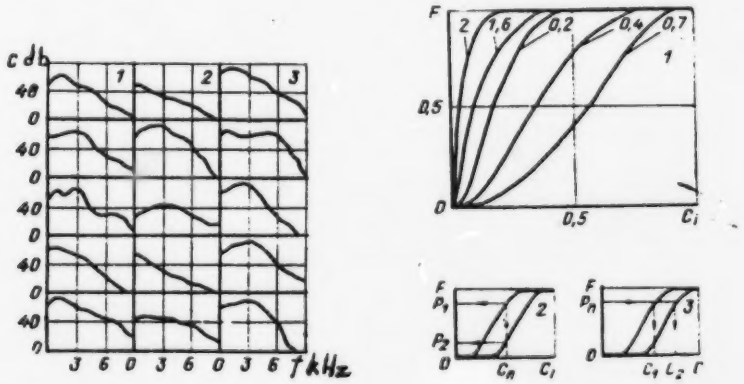

Fig. 1. Spectral power density (C) (energy spectrum) of acoustic signals in pinnipeds, based on five sound signals:

1 - harbour seal, 2 - northern sea-lion, 3 - walrus

Fig. 2. Examples of cumulants of the energy spectra of sound signals in pinnipeds:

1 - family of cumulants corresponding to the frequencies 0.2, 0.4, 0.7, 1.6 and 2 kHz; 2 - plotting of detection characteristics; 3 - plotting of energy spectra; C_i - standardized variables of the dispersion signal, C_n - threshold level of dispersion, P_n - threshold level of probability

This problem was solved by determining the spectral characteristics, which enabled us to detect and describe the signals at the same time. This method is based on the plotting of a family of cumulants (integral functions of distribution) of the energy spectra of the signals emitted by the animals (fig. 2). For the signal frequencies being studied, we calculate the cumulative probability of the variables of the energy spectra hitting the selected classes of the dispersion level in accordance with the standard method of cumulant plotting (Plokhinsky, 1970). In the given case, the cumulant represents the relationship between the probability for not exceeding the dispersions of a spectral component of a certain level and the value of this level. The plotting of cumulants reflects the variability of a characteristic within any range of its values, not only in the region of the mean value, as is the case when the variation coefficient is used; furthermore, the greater the slope of the cumulant, the smaller the variability of the characteristic. In this case, the key characteristics manifest minimum variability. The family of cumulants (fig. 2, 1), which corresponds to different signal frequencies, simply transforms into spectral detection characteristics and threshold energy spectra C. In the first case, we must draw a threshold vertical straight line on the family of cumulants (fig. 2, 2), and reckon the values of the probability for exceeding dispersion of this level. The threshold is determined in such a way that the given probability of spurious signal detection is reached on the basis of the background cumulant which corresponds to a situation where the

signals being studied are not available (Solukha, 1978). On the whole, the entire procedure of plotting the spectral detection characteristics corresponds to the Neuman-Pearson* algorithm. We get the threshold energy spectra when the family of cumulants (fig. 2, 3) is intersected by a horizontal straight line which corresponds to the given threshold probability level (e.g. 0.75 or 0.95).

Results of Investigations and Discussion

The spectral detection characteristics for the two threshold levels (55 db and 65 db) are very similar, but the noise stability of detection at the 65 db threshold is higher, and therefore the reliability of the value is greater. The energy spectra C reflect the relationship between the level of the spectral components and the frequency with 0.95 probability.

Fig. 3 depicts the spectral detection characteristics and the threshold energy spectra C of the members of three families of pinnipeds, i.e. the true seals (the bearded seal and harbour seal), the eared seals (the northern sea-lion) and the walruses, as well as the oscillograms of the sounds typical of each of these animals.

The sound signals of the bearded seal are detected with 0.7 probability in the frequency range of 0.1-0.4 kHz (for the 65 db threshold level). Below 0.1 kHz and above 0.4 kHz, the detection probability decreases sharply, and reaches 0.1 at the frequency of 1.3 kHz. The sound signals of the bearded seal occupy approximately the same frequency range, but their detection probability in the 0.1-0.4 range is equal to 0.8.

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*conjectural spelling - transl.

The spectral signal detection characteristics of the northern sea-lion (family of eared seals) occupy a wider frequency range than the same charactertistics of the true seals mentioned above. The maximum detection probability, which is equal to 0.65, falls within the 0.8-1 kHz frequency range, and decreases to the level of 0.1 at the frequency of 3 kHz.

It is characteristic that the eared seals, who live predominantly in the water, would have a wider frequency range of perceptible sound signals in comparison with the true seals (Bogoslovskaya, Solntseva, 1979). This is due to the presence of a concha auriculae in the eared seals, which ensures frequency trim and, therefore, a much wider frequency range of perceptible signals.

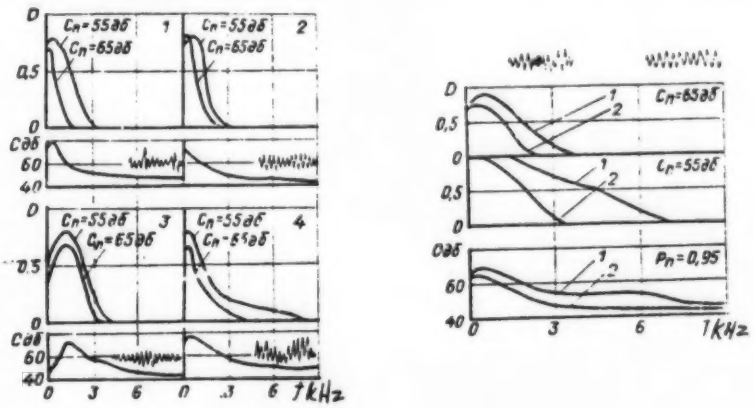

Fig. 3. Detection characteristics and probability spectra C of communication signals in the bearded seal (1), the habour seal (2), the seal-lion (3) and the walrus (4)

Fig. 4. Detection characteristics and the probability spectrum C of communication signals in walruses: 1 - a slowly swimming group of walruses, 2 - after a large rookery enters the water

The sound signals of the walrus occupy a fairly wide frequency range. At low frequencies (about 0.2 kHz), a detection probability of 0.6 gradually diminishes and reaches the zero level at the frequency of 4.5 kHz.

Fig. 4 gives the spectral characteristics of the signals emitted by a slowly swimming group of walruses, which are detected with 0.9 probability in the frequency range of 0.7-1 kHz, and the signals emitted by the same group after entering the water, which reach a detection probability value of 0.7 in the same frequency range. The sound signals typical of these two behaviorally different groups of walruses differ significantly in the maximum value of detection probability and in the frequency range of the emitted signals.

Consequently, the sound signals of the animals can be classified on the basis of the detection characteristics. The simplicity of the classification procedure depends on the frequency band of the emitted signals and on the maximum value of detection probability. From the examples given above, one can easily differentiate the signal spectra at the family level, but it is more difficult to classify the signals at the species level (bearded seal and harbour seal). The energy spectra C of the signals emitted by the animals studied are of the same type, and are far more inferior to the detection characteristics where their classification is concerned.

Conclusions

1. The described method of analyzing the sound signals in species representing three families of pinnipeds makes

it possible to detect and give a spectral description of sound signals at the same time.

2. The walruses have the widest frequency range of signals (0.08-5 kHz), which simplifies the classification procedure.

3. The spectra of the signals emitted by the true seals (bearded seal and harbour seal) lie within the frequency range of 0.08-1.5 kHz, and it is difficult to classify them according to their spectral characteristics.

4. The spectrum of the signals emitted by the eared seals (northern sea-lion) lies within the 0.08-3 kHz range, and is easily differentiated from the signal spectra of the bearded and harbour seals.

5. In animals with a similar structure of the peripheral regions of the hearing system, we also observe similar spectral characteristics of the signals emitted by them.

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SUMMARY

Spectral characteristics of sound signals in representatives of three Pinniped families (Phocidae: *Phoca vitulina*, *Erignathus barbatus*; Otariidae: *Eumetopias jubatus*; Odobenidae: *Odobenus rosmarus*) are analyzed to show their differences. Random time samples of the signals were used as initial material for the analysis. Sound frequency ranges and values of their detection probability are given.

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